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A new type support structure introduction and its contrast study with traditional support structure used in tunnel construction

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ABSTRACT

Referencing the design method of frame-core wall structure used in super high-rise building, a new type supporting system of grid steel frame-core tube was designed, and the structure composition and assembly method for each element were illustrated. A field test was conducted in Jinpingyan tunnel located in the area influenced by 2008 Wenchuan earthquake and the settlement of surrounding rock, internal displacement of surrounding rock, pressure between surrounding rock and primary support, internal force of support arch, axial force of rock bolts, pressure between primary support and secondary lining, and strain of secondary lining were measured to compare under two different support arches of common I-shape steel arch and new type support structure. Moreover, a 3D numerical analyses using FLAC^{3D} software were conducted and the numerical results were compared with results of field test. It was suggested that the new type support structure played a significant role to control the large deformation of surrounding rock.

1. Introduction

Due to the urgent need to improve traffic and to develop environmental friendly infrastructures in western of China, the number of railway tunnels has increased rapidly during the past decades. It is widely accepted that in western of China, with many huge mountains and rivers and the geological conditions is complicated. To meet the increasing demands of China's western region's rapid demographic and economic growth, and to reduce the environmental impacts, railway transportation facilities are extensively constructed over these years. Therefore, more and more railway tunnels are under construction. During the railway tunnel construction, accidents like collapse, water and mud burst, rockbursts, and large deformation appear frequently, which brings great challenges for tunnel construction. Especially for the large deformation represented in weak and weathered surrounding rock, traditional support structures with large stiffness or soft flexibility, such as I-shape steel arch, concrete-filled steel tube arch, grid steel frame, will not play a good role in controlling the larger deformation of surrounding rock effectively.

Moreover, for the tunnel sited in the area occurred earthquake, the effect of earthquake will greatly increase the risks of large deformation during the process of tunnel excavation. Many difficulties for the construction of a tunnel, such as degradation of the surrounding rocks, increased risks for construction, partial decrease in bearing capacity, uneven settlement of the lining structure, and other potential damage for future operation (Li et al., 2005), will be occurred. Many relevant literatures have mainly studied the stability analyses or the distribution of stress and deformation of tunnel surrounding rock under the traditional support structures mentioned above, using the method of analytical methods (Cui et al., 2015; Zanganeh and Kamali, 2013; Wang et al., 2016), model test methods (Fang et al., 2016; Huang et al., 2015, 2013) and numerical methods (Ma et al., 2016; Shen, 2014; Hsiao et al., 2009). Wang et al. (2016) reported a study of the reliability analysis of tunnels using a metamodeling technique based on augmented radial basis function (RBF) and using the function to approximate the implicit limit state/performance functions. Fang et al. (2016) conducted a physical model tests of highway tunnel construction underlying a thin coal seam goaf and under different caved zone-tunnel distances and the inclined coal seam with different dip angles, settlement on the roof and floor of the caved zone and vault settlement of the tunnel during excavation were tested and compared. Shen (2014) conducted numerical modeling to evaluate roadway stability and deformation under

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different roof support scenarios and demonstrated that through careful investigation and optimal support design, roadway stability in soft rock conditions can be significantly improved. Fewer studies focused on the research of new type support structure, which has a better adaptation for the characteristics of large deformation, especially for the large deformation represented in tunnels constructed in earthquake regions.

In this study, referencing the design method of frame-core wall structure used in super high-rise building, a new type supporting system of grid steel frame-core tube was designed, and the structure composition and assembly method for each element were illustrated. A field test was conducted in Jinpingyan tunnel located in the area influenced by 2008 Wenchuan earthquake and the settlement of surrounding rock, internal displacement of surrounding rock, pressure between surrounding rock and primary support, internal force of support arch, axial force of rock bolts, pressure between primary support and secondary lining, and strain of secondary lining were measured to compare under two different support arches of common I-shape steel arch and new type support structure. Moreover, a 3D numerical analyses using $FLAC^{3D}$ software were conducted and the numerical results were compared with results of field test. It was suggested that the new type support structure played an important role in controlling the large deformation of surrounding rock.

2. Engineering background

The Jinpingyan tunnel of Chengdu-Lanzhou high speed railway, located in the 2008 Wenchuan seismic effect area, and adjacent to Songpan town of Aba plateaus, Sichuan Province, China (see Fig. 1). As reported by Yuan (2008), unlike the Tangshan and other devastating earthquakes, the 2008 Wenchuan great earthquake resulted in massive geological disasters. Influenced by Wenchuan earthquake (Xu et al., 2009; Chen et al., 2008), the rock stratums suffered a great destruction and represented a complexity of geological environmental conditions. The Jinpingyan tunnel has a length of 12773 m and a maximum depth of 791 m. The major lithology of tunnel surrounding rock is phyllite. The phyllite rock is intense weathered with very-developed joint fissures and has low strength. The surrounding rock of tunnel was very unstable and easily developed to large deformation. During the construction of tunnel, large deformation with local collapse, concretes shotcrete cracking, primary steel arch distortion and secondary lining cracking, were occurred, as shown in Fig. 2.

The span and height of representative excavation section was 13.7 m and 11.5 m, respectively. It was a large cross-section high-speed railway tunnel. Tri-bench excavation method was adopted, and the construction procedures include top heading excavation, top heading support, benches excavation, and sidewall and invert support. As shown in Fig. 3, the support system was constituted of primary support and secondary concrete lining. The primary support was mainly made up of I-shape steel arch, grouted rock bolts, mesh reinforcement and concrete shotcrete.

3. New support structure introduction

Referencing the design method of frame-core wall structure used in super high-rise building, a new type supporting system of grid steel frame-core tube was designed. As shown in Fig. 4, the new type support structure, grid steel frame-core tube support structure, was consist of three A elements, two B elements, two C elements, two D elements and three E elements. For A, B and C elements, the outside of structure was made up of flexible steel grating, splay structural bar and inside of structure was made up of steel core tube. The physical photos of A, B and C elements were represented in Fig. 5. Through junction steel plate cushioned with rubber blanket, the elements for each other were connected. The steel core tube was connected with steel sleeve. In order to increase the lateral strength of support structure, D element and E element were shaping using I-beam with 20 cm flange width. Grouting tube with 40 cm length was welded to the lower part of C element on both sides and the air hole was reserved on the inner side of middle A element. This offered a convenience for core tube grouting after all the elements were closed.

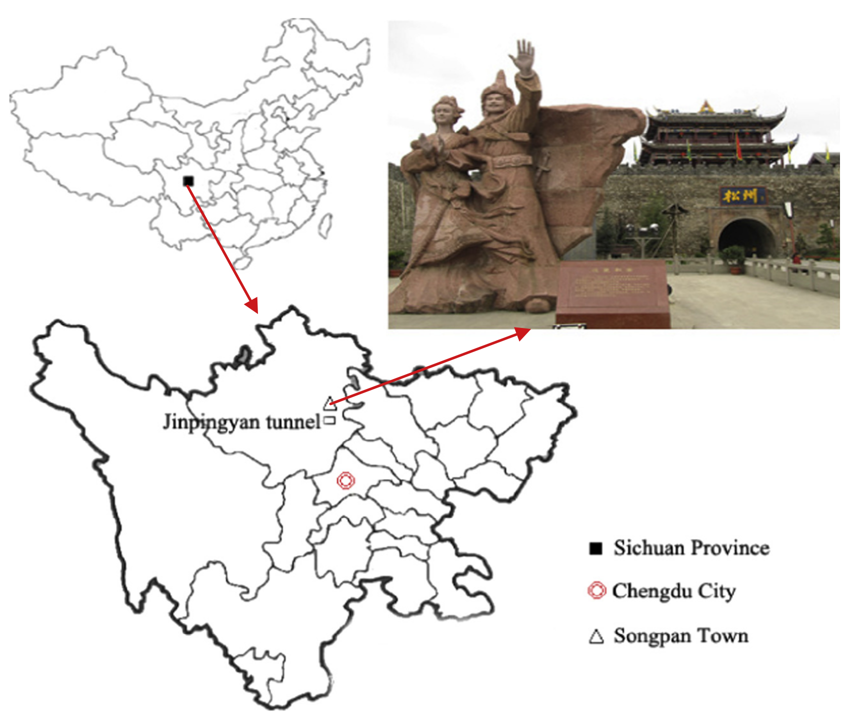

Fig. 1. The location of tunnel under construction.